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Margins of Safety for Aquatic Communities

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16. ABSTRACT

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Margins of Safety for Aquatic Communities

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KEY WORDS: hazard assessment, aquatic toxicology, risk analysis, biological effects

Whether or not the production and use of a particular chemical should be judged safe depends on a wide variety of scientific data, economic benefits and risks, and a considerable amount of value judgment. For purposes of this discussion, let us define margin of safety as being the difference between the expected effect levels and the expected ambient concentrations. Obviously, if everything were known, there would be no need for a margin of safety, because as long as ambient concentrations were less than the effect concentrations safety would be ensured. Clearly, we are never likely to have even most of the information for a precise decision, so that we are forced to allow for errors in our data base and for information that is simply missing because it has not been or cannot be collected. Cairns et al [*1*][2] provide a figurative portrayal of this concept, showing that, as more information is gathered on a chemical, our ability to predict acceptability improves, thus enabling a decision to be made on even smaller differences between the two concentrations.

The illustration given by Cairns et al is useful for setting the stage for further consideration of the elements in deciding on a margin of safety, but it

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[2]The italic number in brackets refers to the reference appended to this paper.

does oversimplify the true situation. Most important, both effect concentrations and ambient concentrations will vary with time and location, so that they should be viewed as concentration bands rather than as constant single values. For example, ambient concentrations will vary depending on the dilution water available, mixing characteristics, variations in daily use or production, degradation rates as affected by seasonal temperatures, and varying treatment efficiencies. The effect concentration will also vary as a result of seasonal changes in toxicity, the presence or absence of specific life stages, the movement of species into or from an area, and community changes such as acclimation. These are only examples of the many factors that cause the effect and ambient concentrations to vary.

Cairns et al [*1*] were not specific about the sources of variation involved in their indicated confidence limits. There are two general sources of uncertainty. One is the experimental error associated with test data. A second and very different type is the absence of important data, for example, the sensitivity of the other organisms that have not been tested or the degradation rates in conditions other than those tested. Distinguishing between these sources is important because no amount of testing to define experimental error better will help in the least to reduce uncertainty about missing information. Recognition of these differences can be a useful guide as to what type of information collection will yield the most useful return for the resources expended.

Figure 1 modifies and expands the concept of Cairns et al [*1*] to depict in more detail and depth a scheme to elucidate the margin of safety. This figure, too, oversimplifies what is likely to be the more common situation. Estimates of the effect and ambient levels are not likely to fit a symmetrical form but will be more irregular. But in a generalized way, this conceptual approach will suffice to illustrate the points I wish to make.

Figure 1*a* is intended to portray the same information as Cairns et al provide [*1*]. Notice that the band of expected ambient concentrations and its confidence limits is wider than that for the effect levels. This is indicative of the greater uncertainty in predicting ambient concentrations and the greater variation to be expected. Evidence to document this statement is hard to cite. Subjectively, I think that standardized methods of measurement for predicting fate are fewer and less proven than those for predicting effects. The factors that decide ambient concentrations seem more numerous and varied. And finally, in spite of many published articles to the contrary, there is weak evidence that one community is very different from other communities in its sensitivity to a chemical. Differences alluded to in other articles are usually based on sensitivity to temperature and nutrients as examples and not on synthetic chemical toxicity.

Note that the slope of the confidence bands diminishes as one proceeds through successive tiers of testing, which suggests that the information gained for a given amount of work diminishes also. For example, when

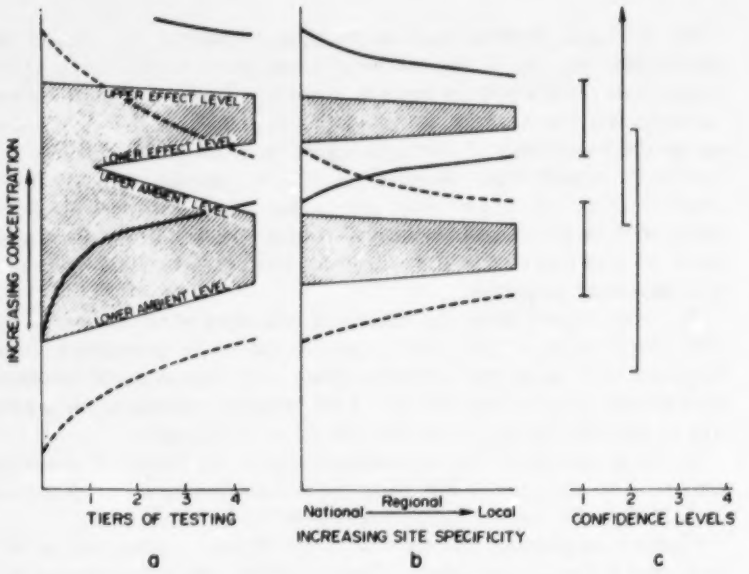

FIG. 1—*Confidence levels associated with predictions of ambient and effect concentrations.*

chronic data are available for two or three species, adding data for a fourth species is not likely to increase substantially the level of confidence or the ability to predict. Likewise, once one has predicted the environmental half-life of a chemical based on microbial degradation, photodecomposition, and hydrolysis, additional laboratory work is unlikely to improve substantially estimates of ambient concentrations for a host of other chemical-physical conditions that are likely to be encountered. We might view testing such as that portrayed in Fig. 1*a* as establishing the "inherent properties" of the chemical (including its biological effect properties), but properties that are less locale specific or species specific.

Figure 1*b* illustrates a second phase of safety-margin estimation based primarily on the degree of site specificity. For example, predicting the "continental" ambient concentration of a chemical will certainly be done with much less certainty for a chemical used throughout the country than for a chemical produced and used in one location and discharged to a small impoundment. The slope of the confidence lines decreases as locale specificity increases, which is indicative of a diminishing return on resources expended to reduce uncertainty. However, at least initially, more is gained by more site specificity than by further testing of the "inherent" properties just discussed. Examples of site-specific considerations are seasonal use, production pat-

terns, discharge patterns (such as multiple discharges), the area of use or production, the size of the receiving water, flow characteristics, receiving water quality characteristics (such as amount of suspended solids), compartmentalization (for example, accumulation in the fat of fish or in sediment versus the water column), the significance of avoidance (Is there an escape location?), stratification, the presence of other stresses such as additional contaminants, and the particular species that will actually be exposed. All or many of these effects can be judged or measured only in site-specific situations; yet they may change the ambient or effect concentration far more than the "inherent" properties.

Just when work is more cost effective if concentrated on site-specific evaluation rather than on "inherent" properties cannot be generalized. Intuitive judgment must guide most of that decision. Such factors as the variability of data already gathered and the size of the geographical area of use are examples of relevant considerations that will aid in the decision.

In Fig. 1*c* two different sets of confidence levels are illustrated: one is equivalent to those portrayed in Fig. 1*a* and *b*, and another set is chosen to be arbitrarily larger. Of course, many others could also be considered.

Figure 1*c* emphasizes that there is no one confidence level, such as 95 percent, that is always appropriate. There is nothing conclusive about a 95 percent confidence level; its frequent use is only a habit. After testing, data collection, and synthesis are completed, a decision needs to be made as to the appropriate confidence level to be used. In Fig. 1*c*, confidence intervals are intended to depict primarily unknown information and not experimental error. Much of this uncertainty includes value judgments involving social ethics and economic cost/benefit ratios. Many uncertainties fit logically into this category. Examples are (1) the similarity of tested conditions to real-world ones; (2) the probability of use pattern changes or expanded use; (3) the geographical area of use, such as household use or nationwide versus local use for a specific manufacturing process; (4) the hazard to humans, such as a bioaccumulable carcinogen versus a degradable, low-toxicity, and water-soluble chemical; (5) the likelihood that endangered species will be exposed or that unique historic or scientifically valuable sites will be contaminated; (6) the spread in sensitivity of tested species—if large, one should expect an even larger uncertainty about the spread in the untested species; (7) the functional value to the community of tested species—if ecologically critical groups have not been tested, a higher confidence is needed; (8) the persistence, since more persistent chemicals are a greater threat than less persistent ones; (9) the probability that unexpected chemical transformations may occur, such as methylation of metals or increased mobilization; (10) the conspicuousness of effects, since this determines the probability of observing harmful effects; and, finally, (11) the consequences of making an incorrect decision, whether rejecting an acceptable chemical (mostly economic and social effects) or accepting one that is harmful (mostly health and environment effects).

Many past controversies that have appeared to revolve around differences of data interpretation or contradictory data really depend on defining acceptable risks—that is, appropriate confidence levels or margins of safety. In fact, disagreement over appropriate confidence levels (margin of safety) may well be the most important single ingredient determining the final decision. As shown in Fig. 1*c*, if confidence Level 1 is used, the situation depicted might be considered to have an ample margin of safety, whereas if Level 2 is chosen the decision might well be negative. A decision as to what confidence levels are appropriate could be defined in large part by law, such as the Endangered Species Act, which would require the selection of a degree of confidence approaching 100 percent.

Most important, much of the authority for confidence-level selection rests principally in the public domain where scientists hold no privileged power or insight. In fact, some issues that are important in confidence-level selection (margin of safety) lend themselves dramatically to strong biases which lead to different perceptions of appropriate confidence. For example, regulators fearing public outcry opt for high confidence levels (Level 2 on Fig. 1*c*), and registrants seeking profit and market advantage opt for lower limits (Level 1 on Fig. 1*c*).

Recognition of the significance of these biases and the importance of these value judgments, by scientists especially, would do much to minimize disagreement between "sides" and focus attention on the root problem. Indeed, the observable fact that scientists working for regulatory agencies usually support the agency decisions whereas those working for the industries regulated tend to oppose regulatory decision is not coincidence! Perhaps the most important reason for this phenomenon is a difference in perception of the appropriate confidence level and not disagreement over data. Identifying and putting in place efficient mechanisms to resolve biases and differing value judgments in the selection of the best confidence levels might do as much to enhance the establishment of safety margins as more embryo-larval tests, daphnia chronic tests, or fate testing.

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Reference

[1] Cairns, J., Jr., Dickson, K. L., and Maki, A. W. in *Estimating the Hazard of Chemical Substances to Aquatic Life. ASTM STP 657*, American Society for Testing and Materials, Philadelphia, 1978, pp. 191-197.